TI Designs
Sub-1GHz Low Cost Mesh Network Design Guide

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Design Resources

TIDU546A	Tool Folder Containing Design Files
MSP430G2533	Product Folder
CC1101	Product Folder

TI E2E™ Community — ASK Our E2E Experts
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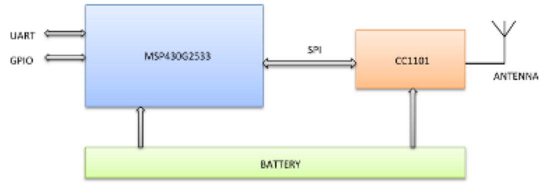
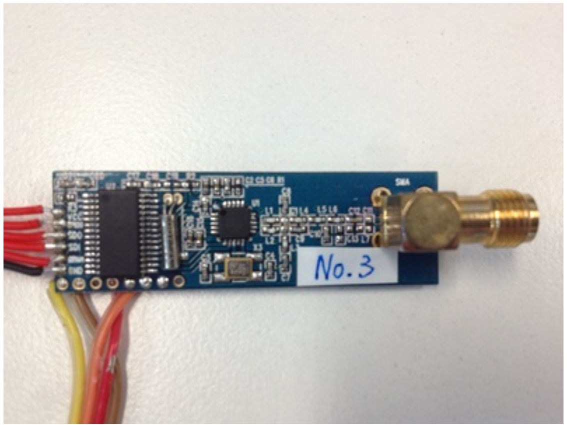
Design Features

- Self-organization, self-maintenance, no manual collocation needed
- Multi-hop communication to enlarge network coverage
- Multi-routed to avoid the effect of the failure of a single node
- Low cost, low power consumption
- Combination of on-demand query and periodical report
- Turnkey solution for IoT applications

Featured Applications

- Building Automation
- Factory Automation and Control





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1 System Description

This solution uses the MSP430G2533 and CC1101 to implement a mesh network within the sub-1 GHz frequency band.

1.1 MSP430G2533

The Texas Instruments MSP430 family of ultra-low power microcontrollers consists of several devices, featuring different sets of peripherals targeted for various applications. The architecture, combined with five low power modes, is optimized to achieve extended battery life in portable measurement applications. The device features a powerful 16-bit RISC CPU, 16-bit registers, and constant generators that contribute to maximum code efficiency. The digitally-controlled oscillator (DCO) allows wake-up from low-power modes to active mode in less than 1 µs.

The MSP430G2x33 series are ultra-low-power mixed signal microcontrollers with built-in 16-bit timers, up to 24 I/O capacitive-touch enabled pins, and a built-in communication capability using the universal serial communication interface. In addition, the MSP430G2x33 family members have a 10-bit A/D converter.

Typical applications include low-cost sensor systems that capture analog signals, convert them to digital values, and then process the data for display or for transmission to a host system.

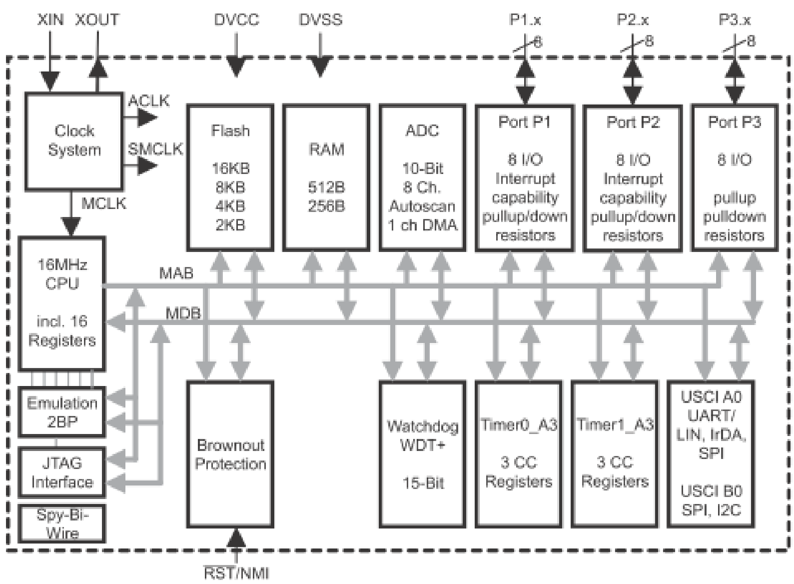

Figure 1. Functional Block Diagram, MSP430G2x33

1.2 CC1101

The CC1101 is a low-cost sub-1 GHz transceiver designed for low power wireless applications. The circuit is primarily intended for the ISM (Industrial, Scientific and Medical) and SRD (Short Range Device) frequency bands at 315, 433, 868, and 915 MHz, but can easily be programmed for operation at other frequencies in the 300-348 MHz, 387-464 MHz and 779-928 MHz bands.

The RF transceiver is integrated with a configurable baseband modem. The modem supports various modulation formats and has a configurable data rate up to 600 kbps. The CC1101 provides extensive hardware support for packet handling, data buffering, burst transmissions, clear channel assessment, link quality indication, and wake-on-radio.

The main operating parameters and the 64-byte transmit/receive FIFOs of the CC1101 are controlled using an SPI interface. In a typical system, the CC1101 is used together with a microcontroller and a few additional passive components.

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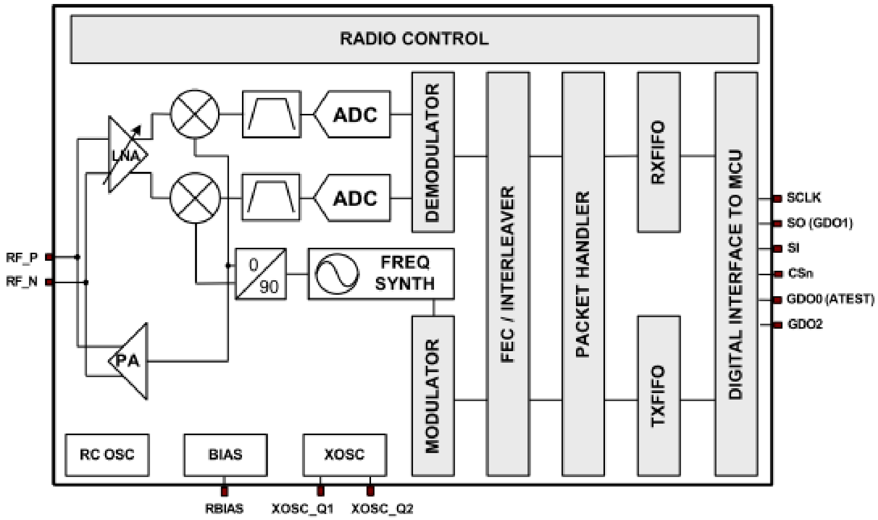

Figure 2. CC1101 Simplified Block Diagram

2 Block Diagram

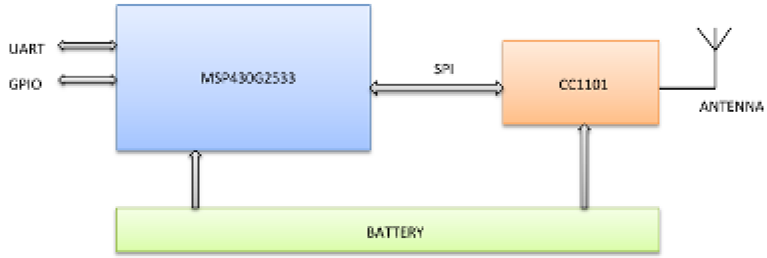

Figure 3. Block Diagram

3 System Design Theory

There are two kinds of devices in the network, a master node and several slave nodes. The master node is used as data collector. There is only one master node in each network. The master node establishes, manages, and maintains the network. The master node stores connection link information of the entire network for routing wireless packets.

Typically, a slave node is connected to one or more sensors. A slave node gets desired information from associated sensors and sends the sensing data through the network to the master node. The number of slave nodes depends on the size of the network. Routing data is not stored in slave nodes. The only information stored in a slave node is the address of its father-node, which is used when actively reporting time-sensitive data, such as an alarm.

On-demand query and periodical active report are supported when the communications in the network are divided into two parts, the downlink and uplink. Downlink contains all communications initiated by the master node. Uplink contains all communications initiated by the slave nodes.

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3.1 Master Initiated Operation

After power on, the master node broadcasts a discovery frame. The slave node that receives this broadcast frame joins the network and marks itself as an in-net slave node, and responds to the sender. Periodically, the master node resends the broadcast frame and calls all in-net slave nodes in turn, to broadcast for new nodes and new connections. The master node maintains a link table, which records connections between every two nodes in the network. The master node uses this link table to get the route from the master node to each slave node.

The master node can call any in-net slave node to query for its data. The query frame contains the entire route from the master node to the slave node, including intermediate relay slave nodes. The queried slave node responds with its data to the master node by reversing the route contained in the query frame.

3.2 Slave Initiated Operation

After power on, the slave node broadcasts a join request frame. When the master node or any in-net slave node receives this request frame, it replies with a join response, and reports this newly-established connection to the master node. After receiving the join response, the requesting slave node marks itself as an in-net slave node.

An in-net slave node can actively report data to the master node periodically. The slave node forwards the data frame to its father node (the node which allows it to join the network). The receiver also forwards the data frame to the father node of the receiver. Eventually the data frame is forwarded to the master node.

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4 Getting Started Hardware

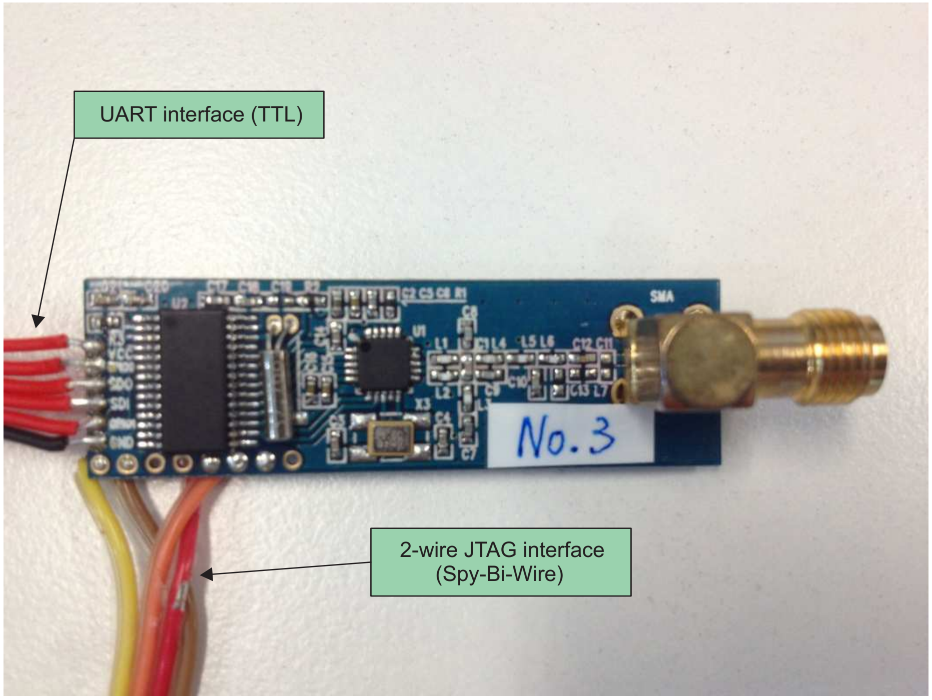

Figure 4. JTAG Connection and UART Connection

4.1 *JTAG Connection*

To download the program into flash, use the connections between PCBA and JTAG listed in Table 1:

Table 1. PCBA and JTAG Connections

PCBA	JTAG
VCC (Pin-1, Yellow)	VCC_TOOL (Pin-2)
GND (Pin-2, Brown)	GND (Pin-9)
TEST (Pin-5, Red)	TCK (Pin-7)
RESET (Pin-6, Orange)	TDO/TDI (Pin-1)

4.2 *UART Connection*

To observe network performance, the master node prints topology information and received data through UART. Use the connections between PCBA and PC listed in Table 2. Note: the UART uses TTL level, and should be converted to the RS232 level before the PC can recognize it.

Table 2. PCBA and UART Connections

PCBA	PC UART
SDO (Pin-3)	RXD
SDI (Pin-4)	TXD
GND (Pin-6)	GND

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5 Getting Started Firmware

Follow the steps below to download the firmware into flash.

5.1 Open IAR Project

Double click the project file, and open the project.

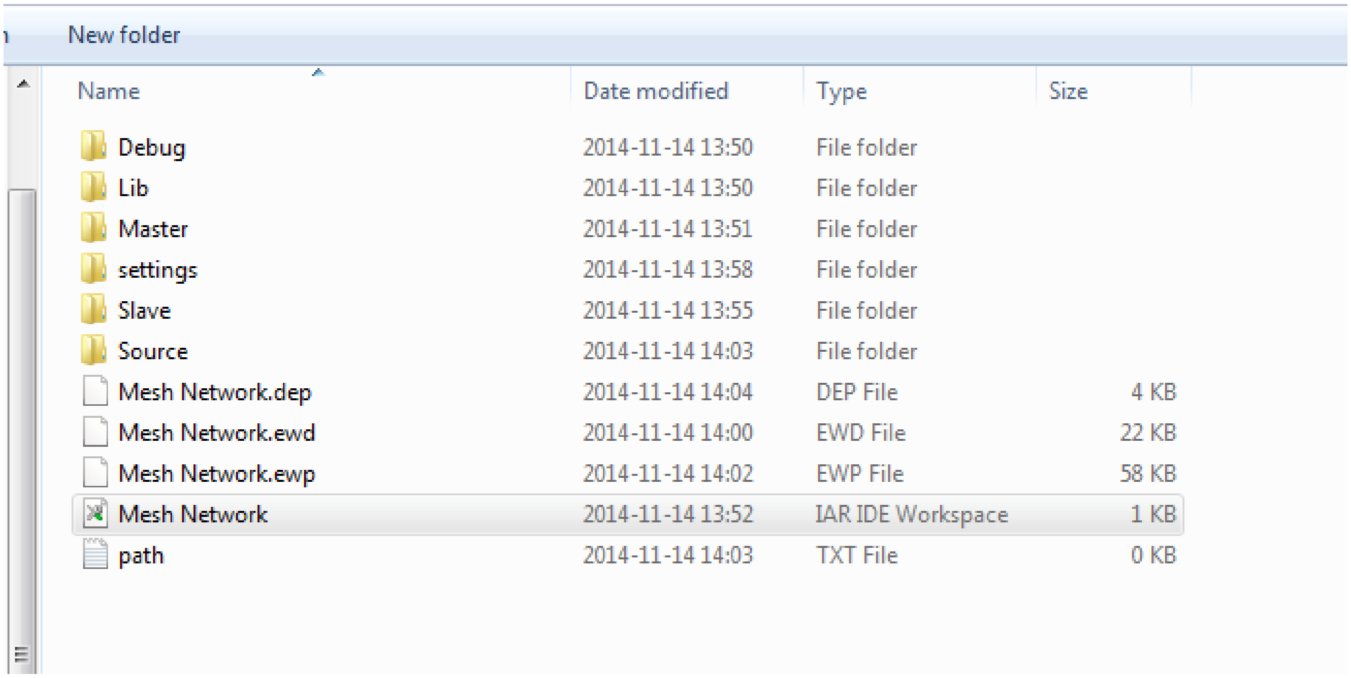

Figure 5. Project File Folder

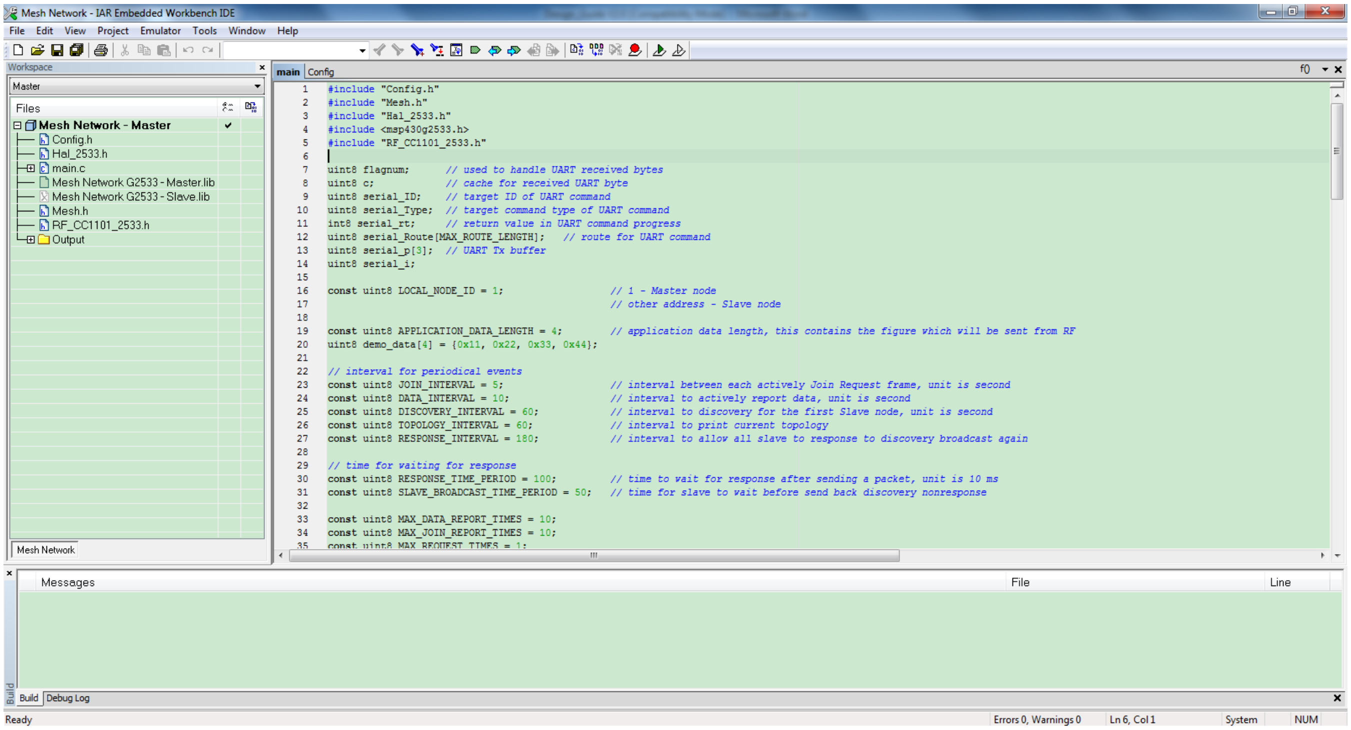

Figure 6. IAR Project

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5.2 Master Node

To download firmware into the master node, follow these steps:

1. Select the Master configuration in the ComboBox (See Figure 7)
2. Comment line 5 in Config.h. (See Figure 8)
3. Change the value of constant LOCAL_NODE_ID to 1 to assign node address to master node. (See Figure 9) (Note: The master node should be assigned address 1, and address 0 is reserved for broadcast address. Slave nodes can use addresses 2 – 255.)
4. Rebuild the project and download into Flash of the master node.

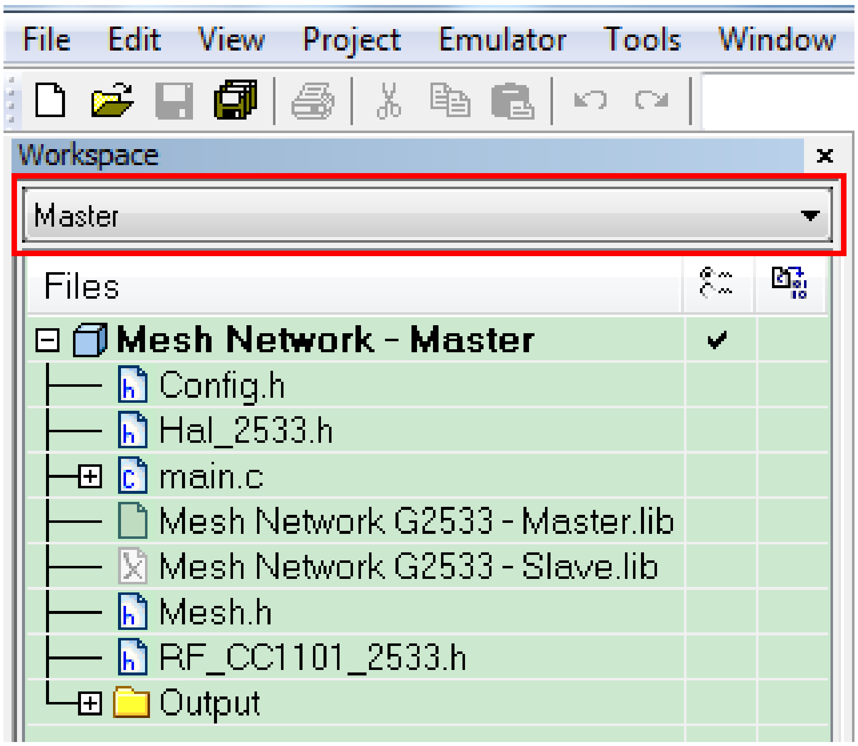

Figure 7. Select Master Configuration

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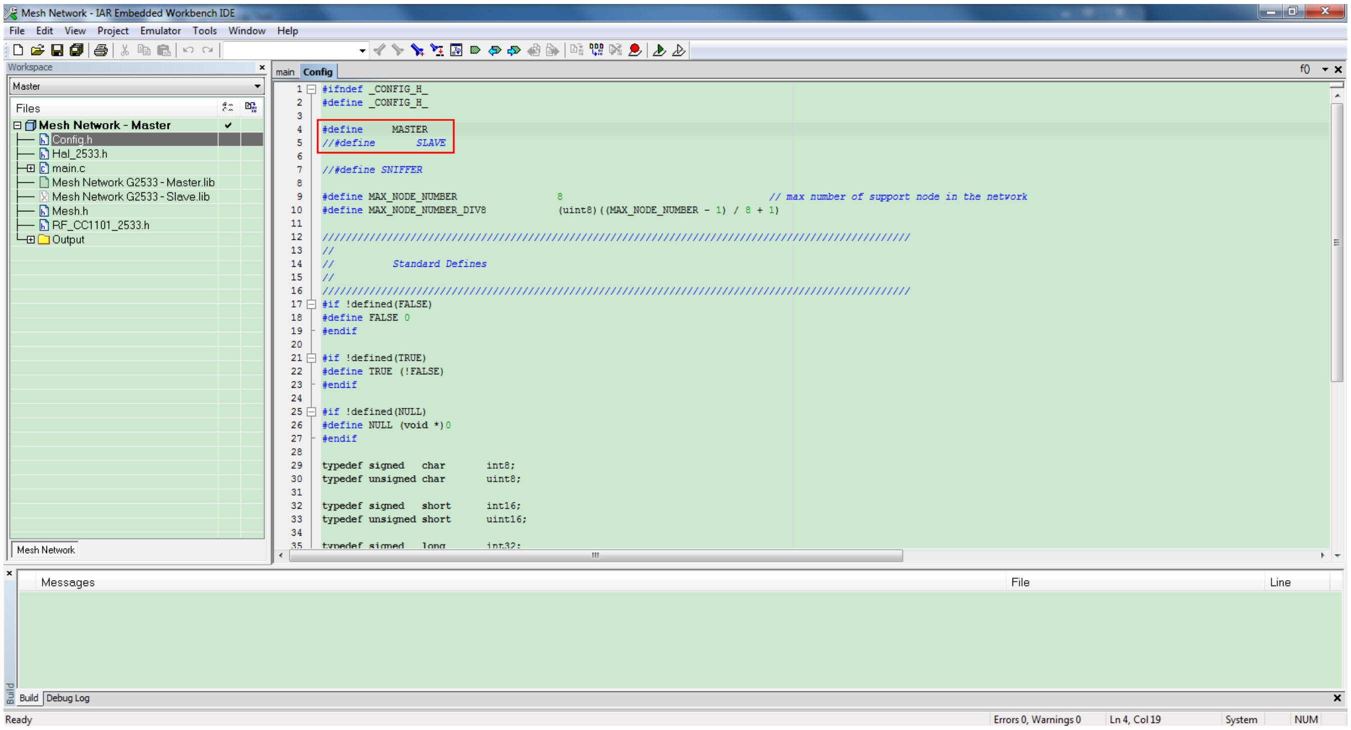

Figure 8. Choose Master Macro Definition

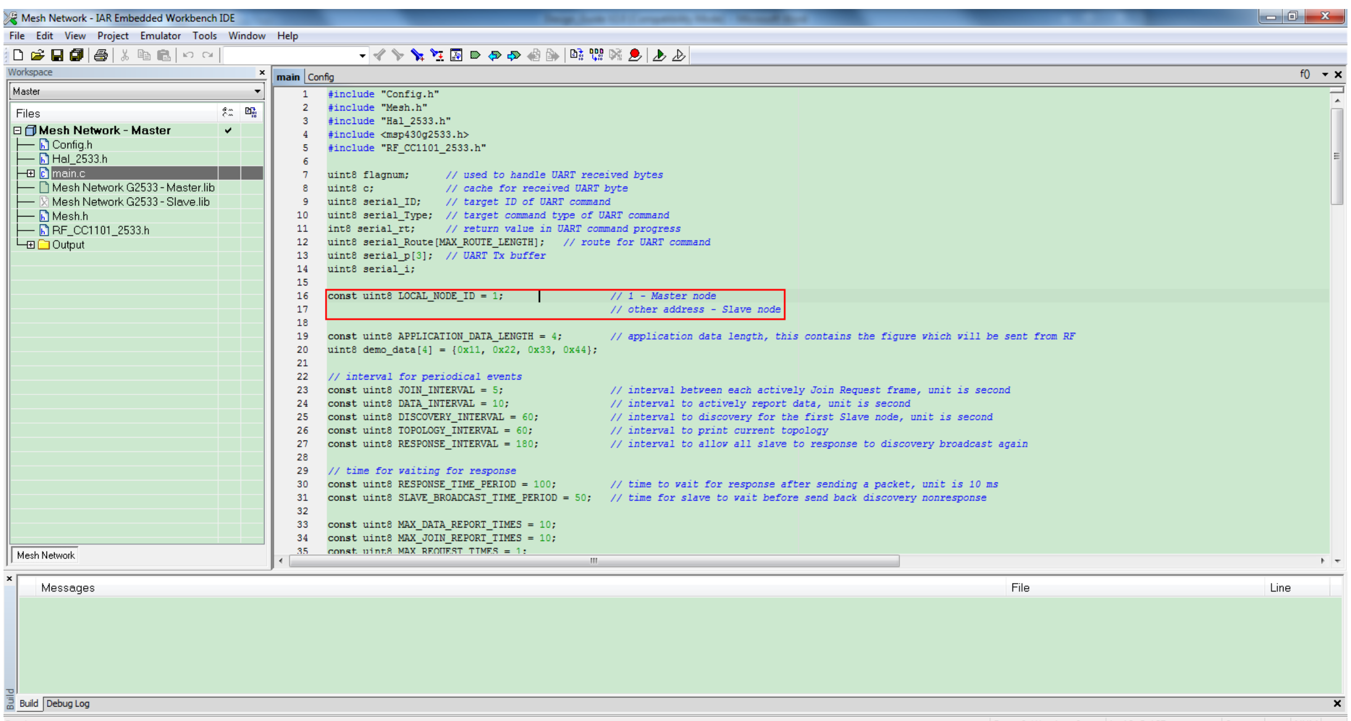

Figure 9. Assign Node ID to Master Node

5.3 Slave Node

To download firmware into slave nodes, follow these steps:

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1. Select the Slave configuration in the ComboBox. (See Figure 10)
2. Comment line 4 in Config.h. (See Figure 11)
3. Change the value of constant LOCAL_NODE_ID to desired node ID to assign node address to each slave node. (See Figure 12) (Note: The master node should be assigned address 1, and address 0 is reserved for broadcast address. Slave nodes can use addresses 2 – 255.)
4. Rebuild the project and download into Flash of each slave node.

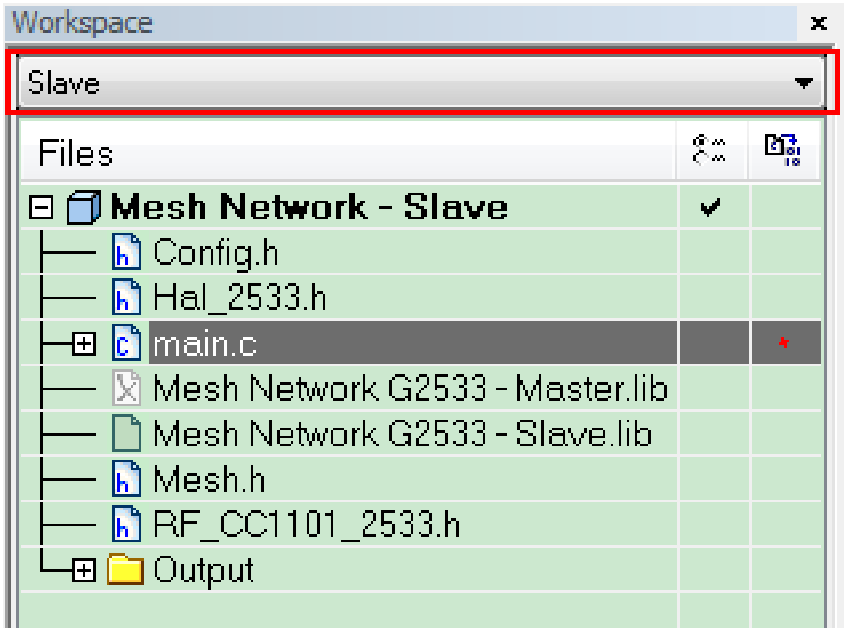

Figure 10. Select Slave Configuration

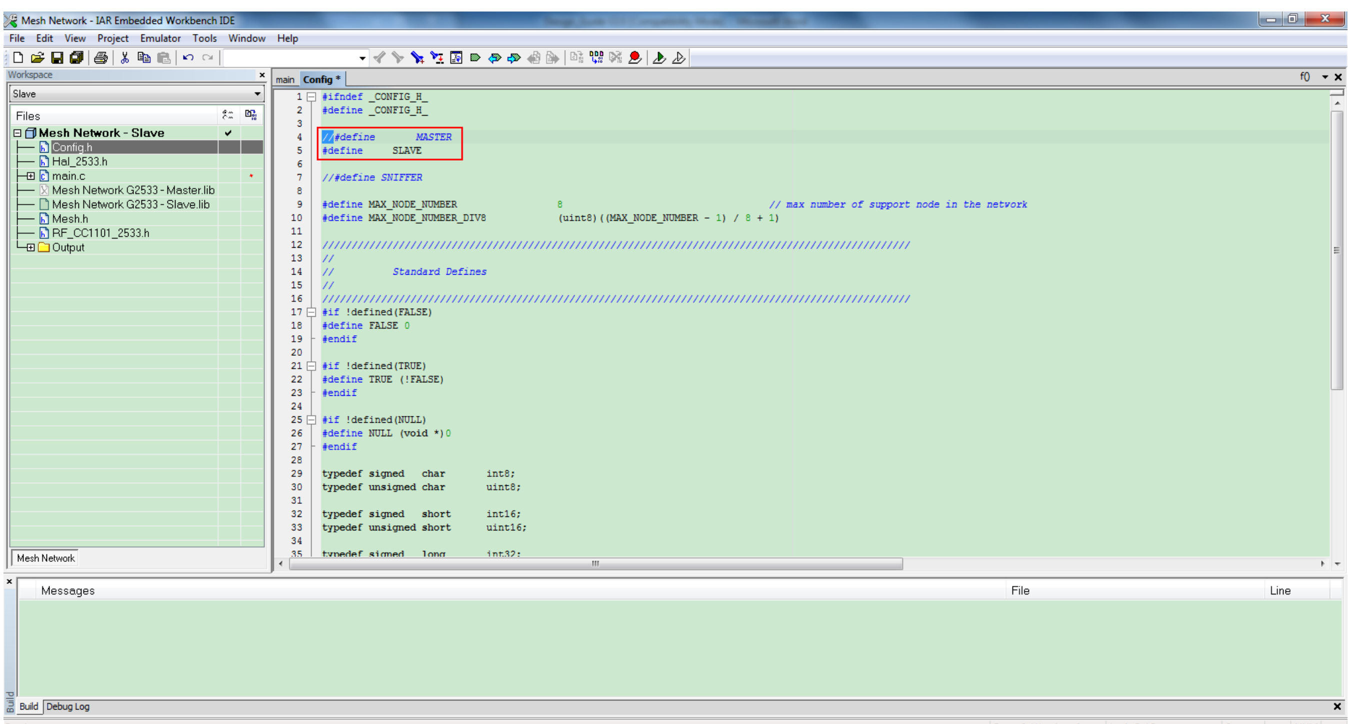

Figure 11. Choose Slave Macro Definition

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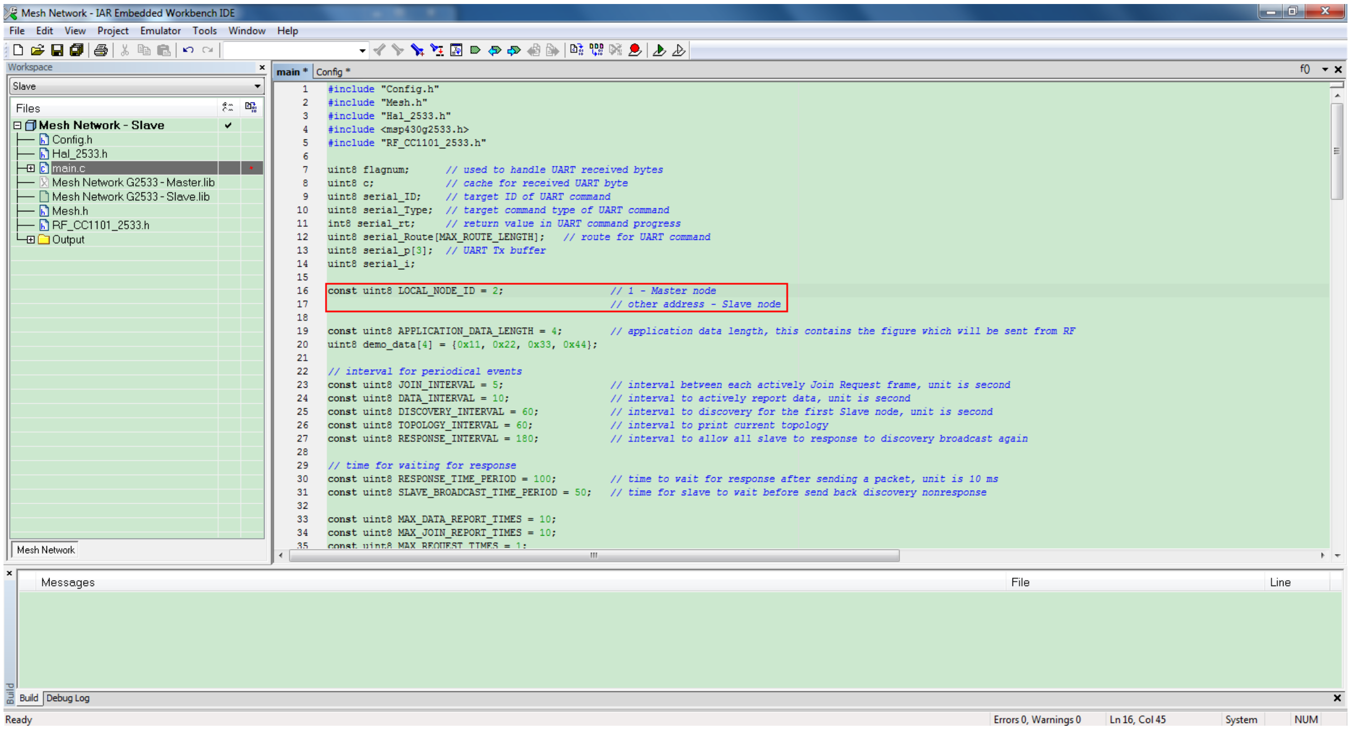

Figure 12. Assign Node ID to Slave Node

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6 Test Setup

In this test, a master node (addressed No.1) and 7 slave nodes (addressed No.2 – No.8) are used in this demo.

6.1 GUI

Open the GUI, select the proper COM port, set the baud rate to 9600, and click Open to open the COM port. COM Data area displays all frame master node receives. Query command and maintenance information also display in this area. Received Data area displays decoded data frame master node receives. The Link Table area displays all connections established between each two nodes in the network. The Route Table area displays routes from the master node to each slave node.

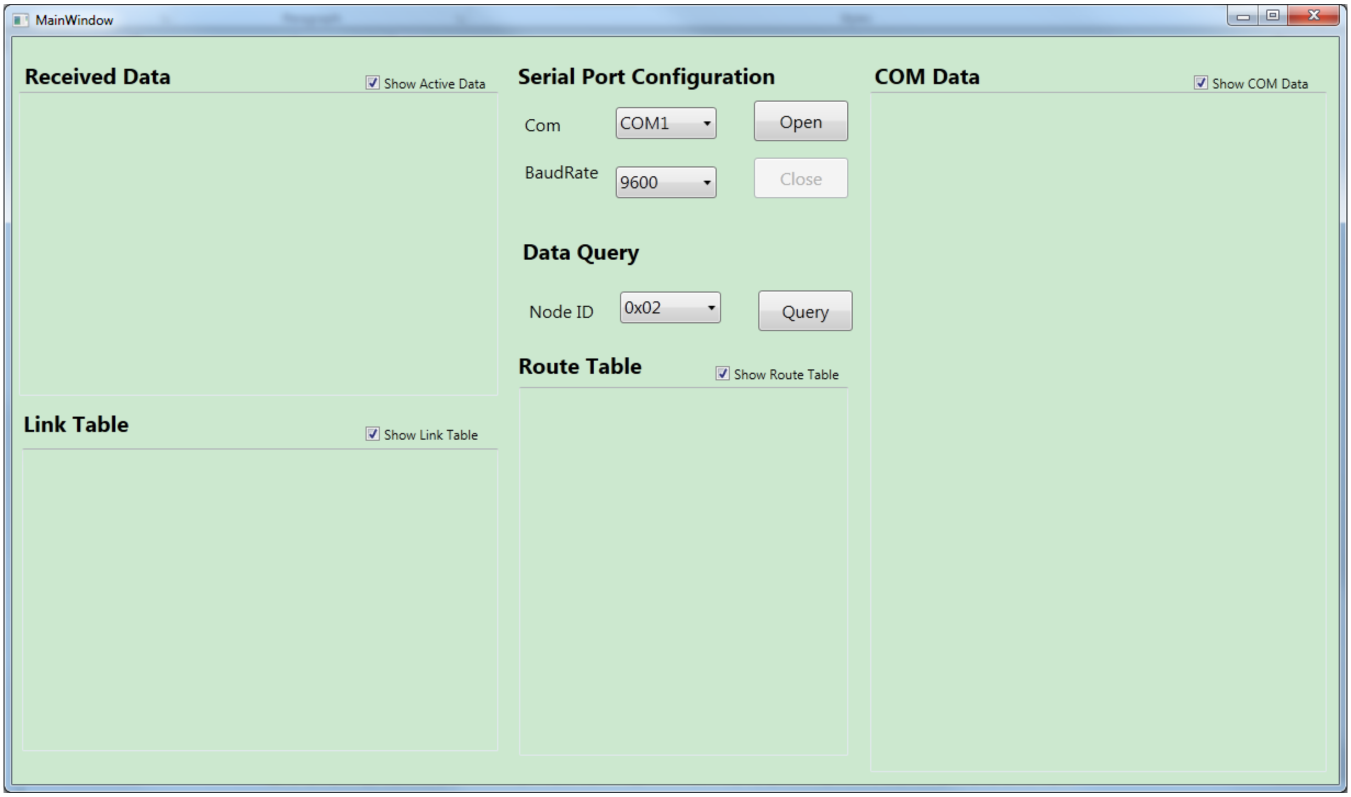

Figure 13. GUI

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6.2 Power On

Switch on master node and all slave nodes. The network is set up automatically immediately after all nodes power on. Slave nodes actively try to join the network. Nodes which are already in-net report new connections to the master node.

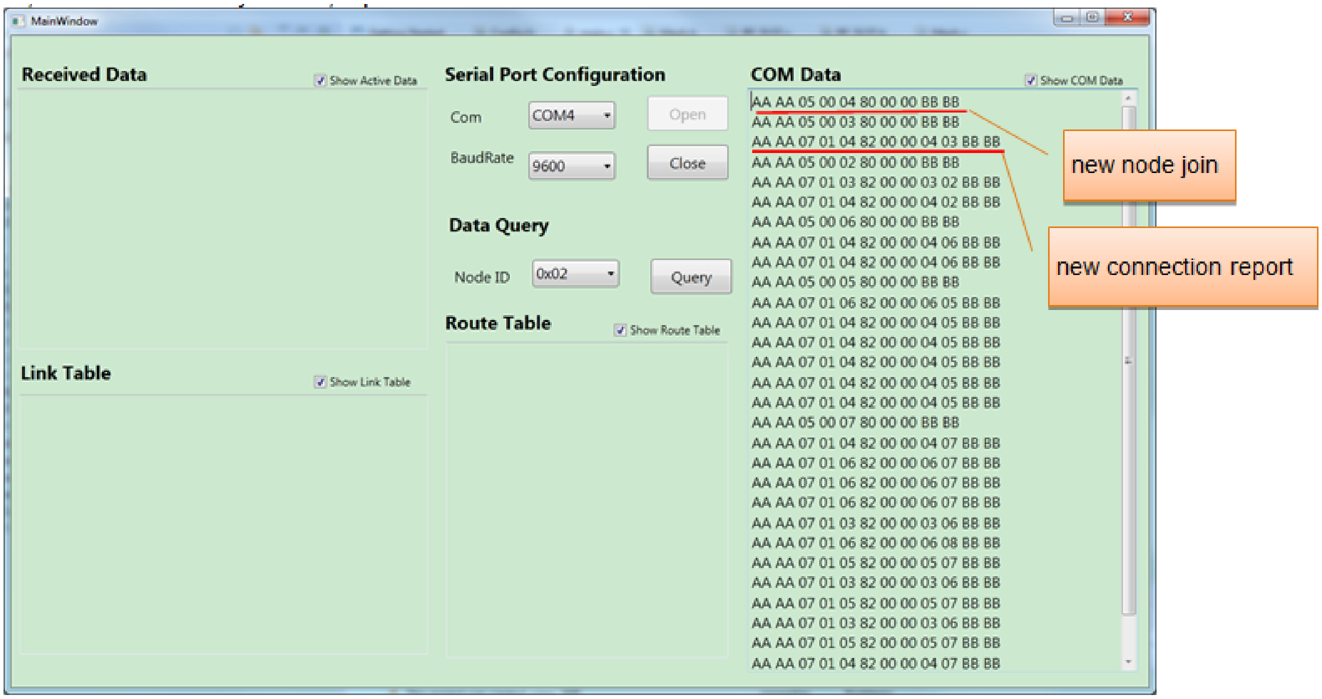

Figure 14. Power On

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7 Test Data

7.1 Initial Topology

All nodes join the network quickly after power on. The initial topology is established and maintained by the master node. Routes are found from the master node to each slave node.

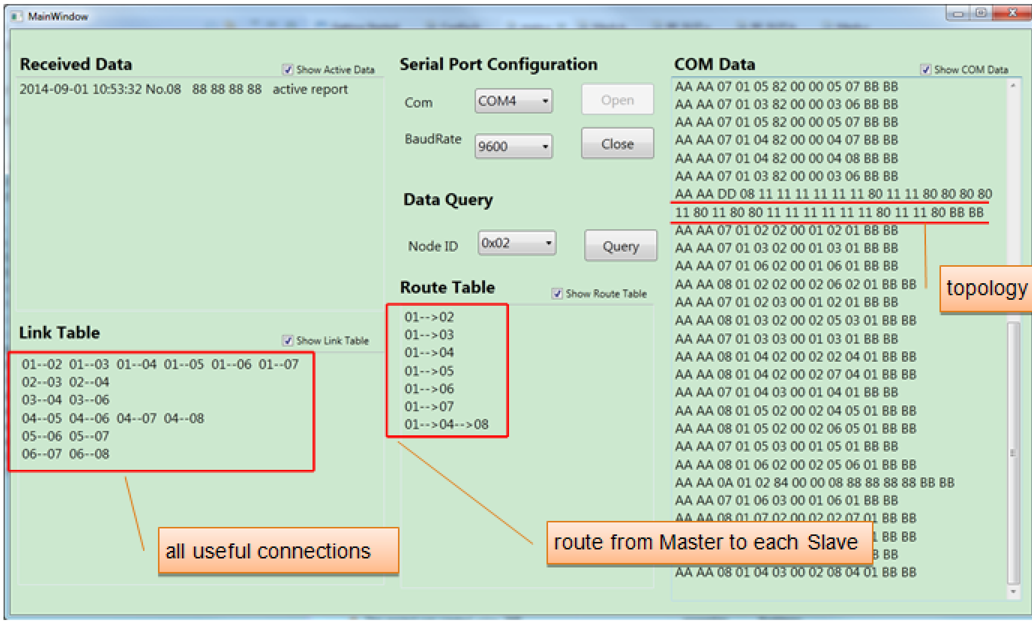

Figure 15. Initial Topology

7.2 Topology with More Connections

More connections are established by discovery, initiated by the master node. Each slave node actively reports data to the master node every minute.

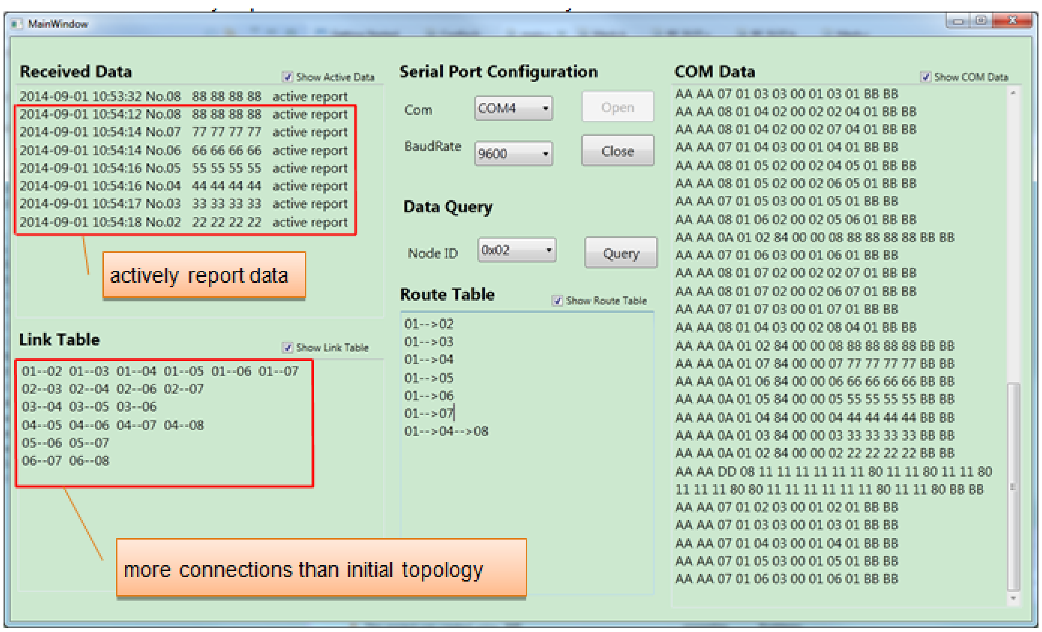

Figure 16. Topology with More Connections

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7.3 Respond Discovery Broadcast

Each slave node is called by the master node to generate a discovery broadcast and find more connections. Any new connections are reported to the master node.

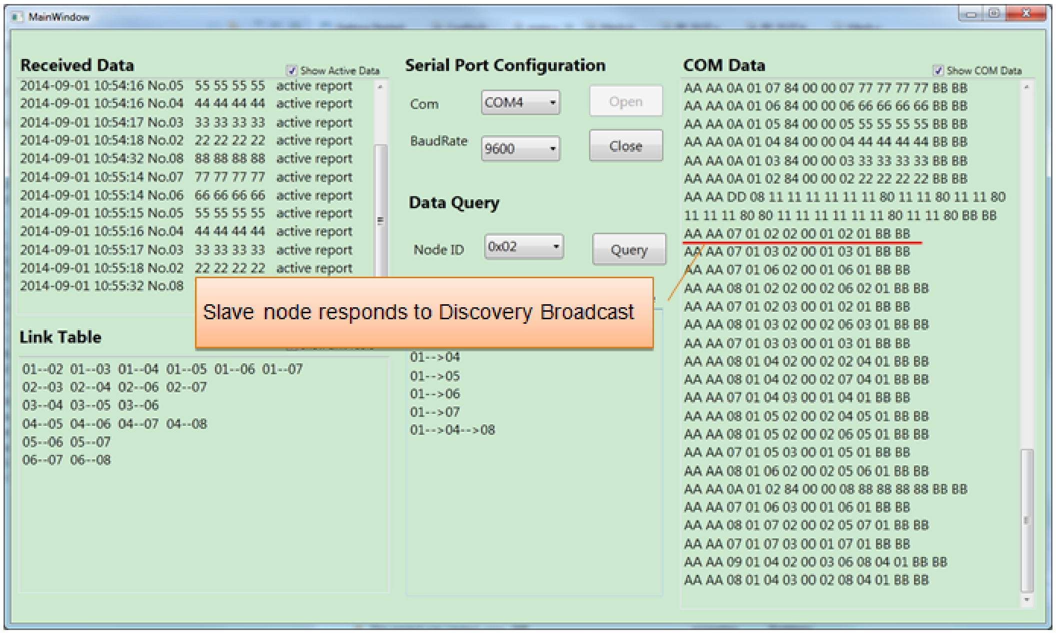

Figure 17. Respond Discovery Broadcast

7.4 Data Request and Response

Each node can be queried for its data in an on-demand pattern.

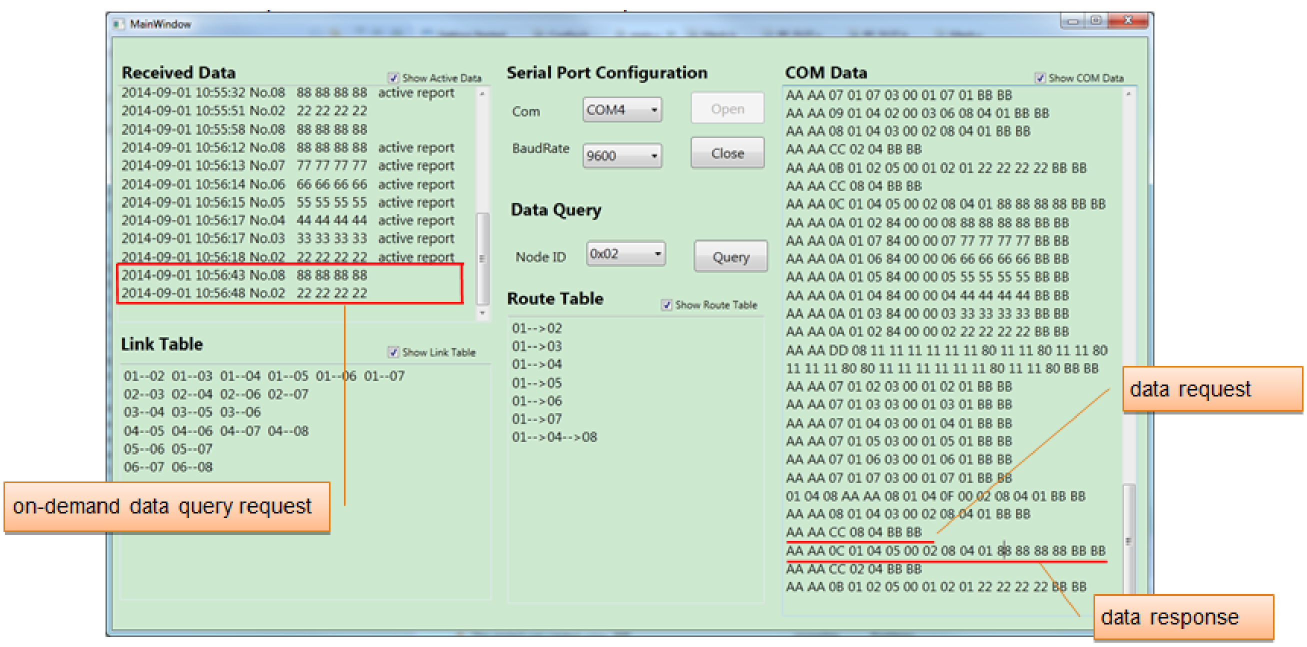

Figure 18. Data Request and Response

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7.5 New Route used between No.1 and No.8

The route between No.1 and No.8 is replaced, from No.1 -> No.4 -> No.8, to No.1 -> No.2 -> No.8, as a new connection between No.2 and No.8 is established.

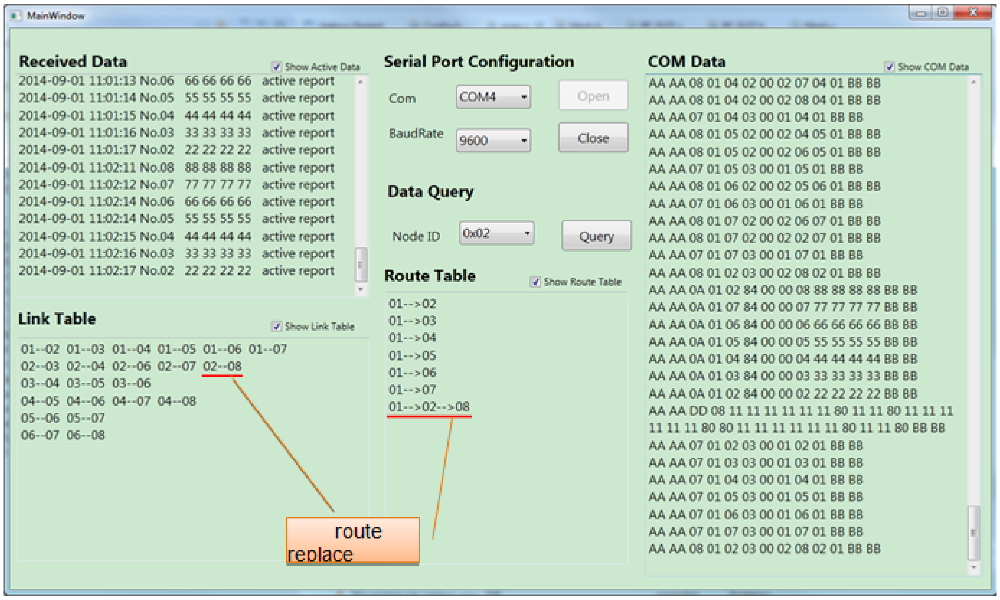

Figure 19. New Route used between No.1 and No.8

7.6 New Connection found between No.3 and No.7

A new connection between No.3 and No.7 is established during periodic network maintenance.

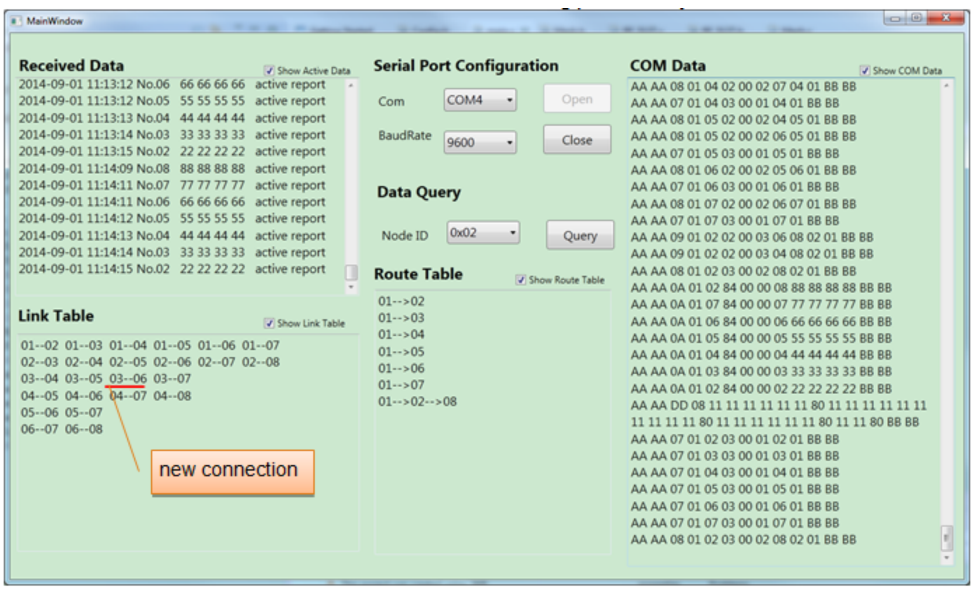

Figure 20. New Connection found between No.3 and No.7

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7.7 Call Each Slave Node for Data

Call each node in turn to query for data in an on-demand pattern.

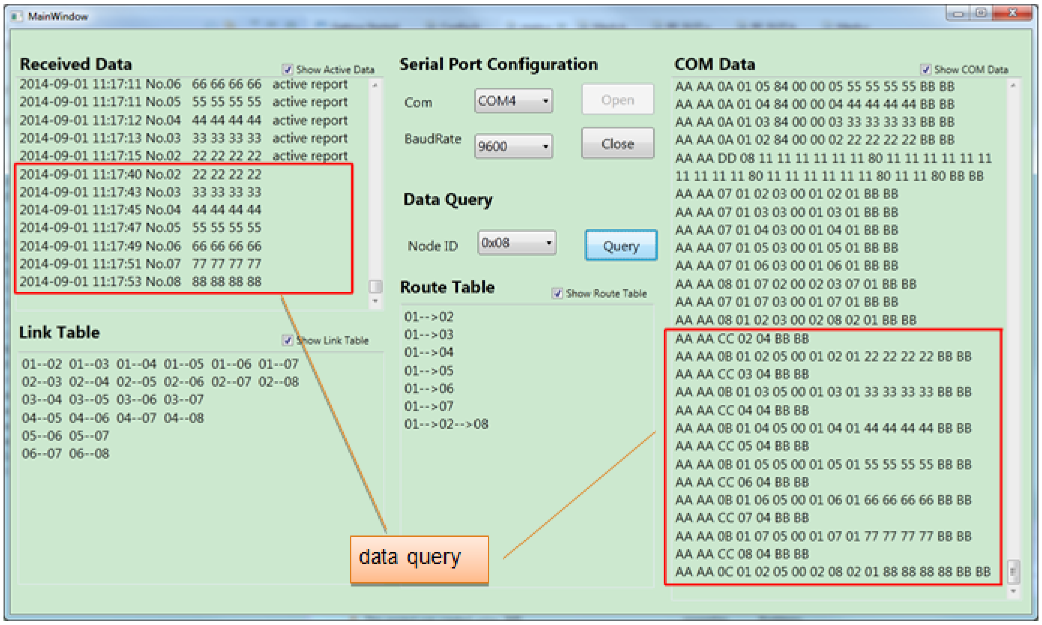

Figure 21. Call Each Slave Node for Data

7.8 Slight Topology Change

Connections between nodes continually change during operation, as wireless communication is easily influenced. The route table, however, remains stable with only slight changes in topology.

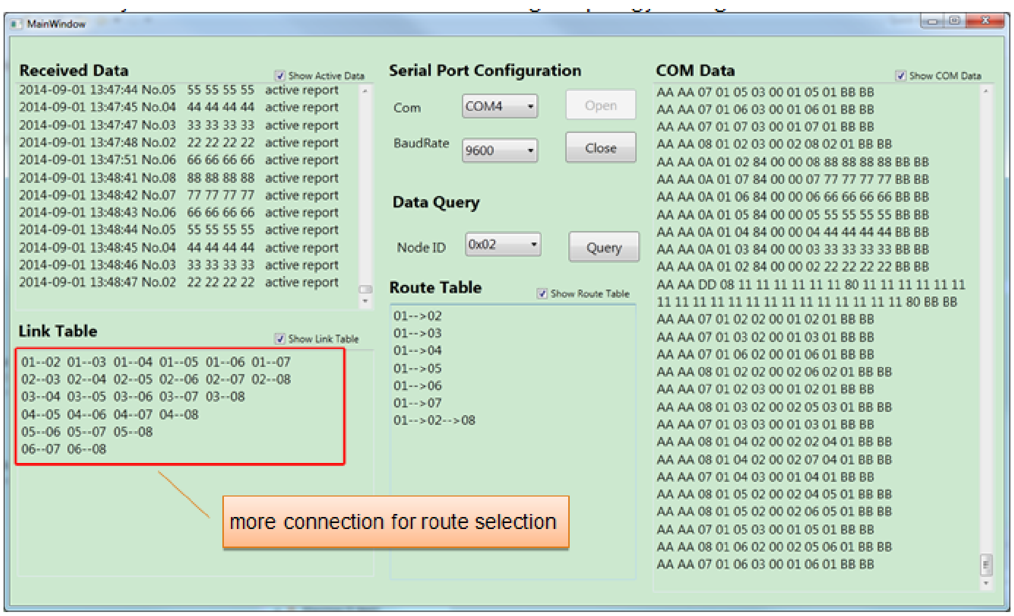

Figure 22. Slight Topology Change

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7.9 After Two Hours Running

Call each node in turn to query for data in an on-demand pattern and get the desired response.

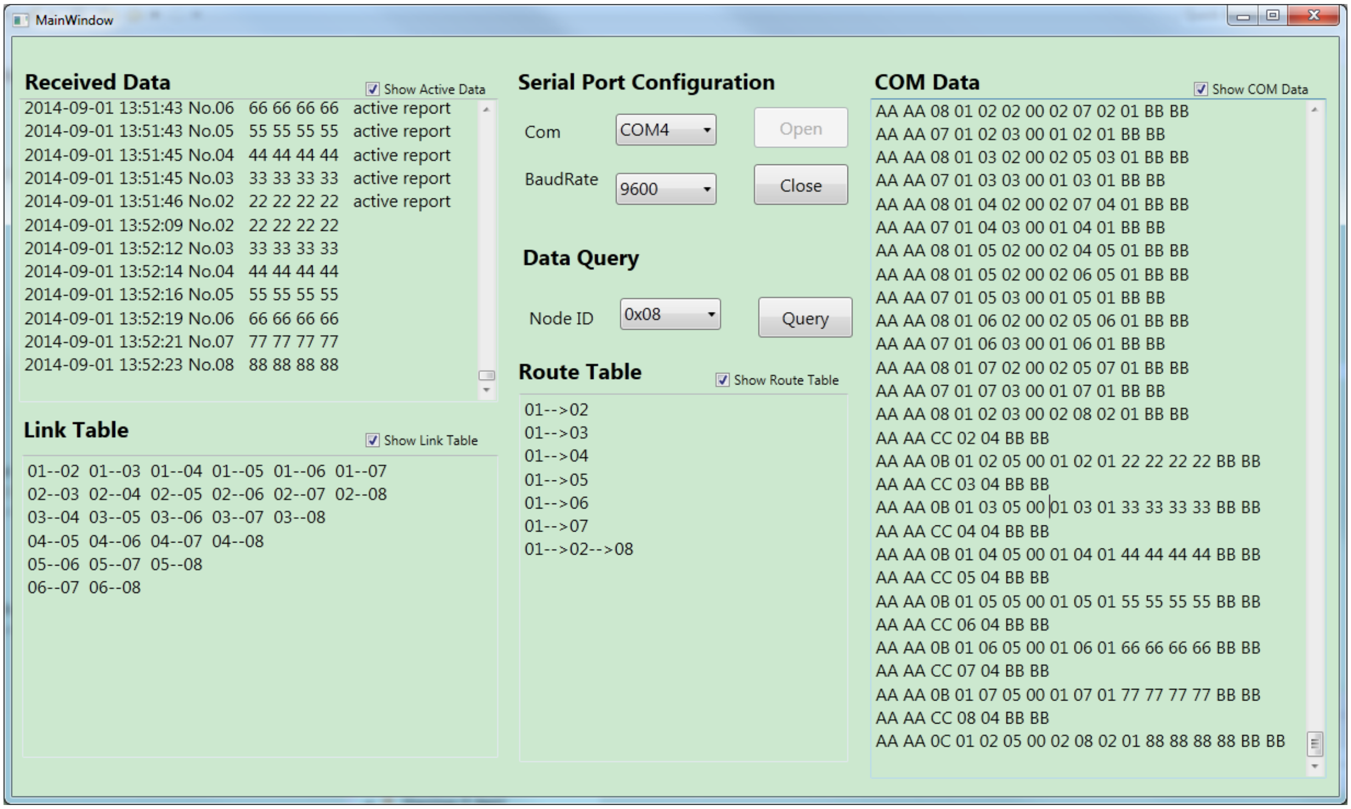

Figure 23. After Two Hours Running

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8 Design Files

8.1 Schematics

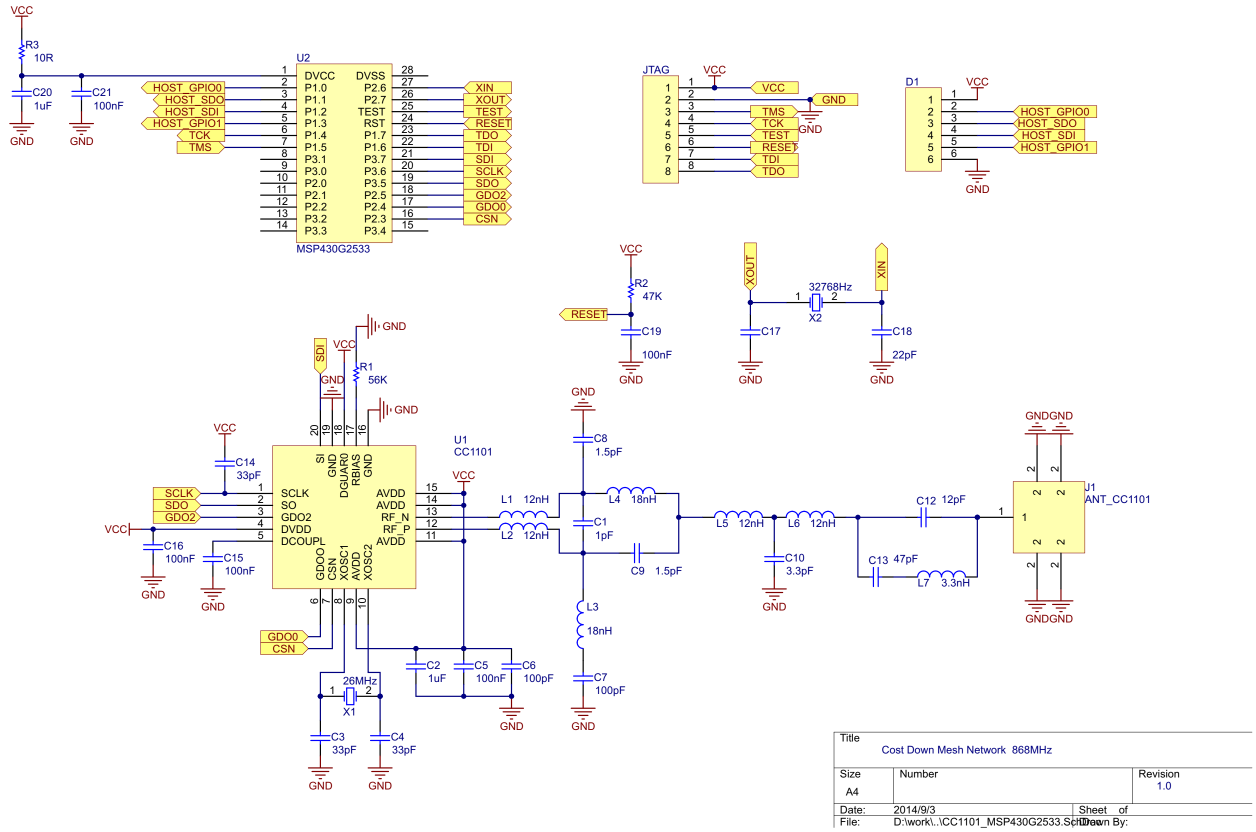

Figure 24. Schematic

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8.2 Bill of Materials

Table 3. BOM

Item	Qty	Reference	Value	Part Description	PCB Footprint
1	1	X1	26 MHz	Crystal Oscillator	XIAL4P-SMT3*2X5
2	1	X2	32768 Hz	Crystal Oscillator	XIAL-2*5V - noSMT
3	1	C1	1 pF	Capacitor	C/0402
4	2	C2, C20	1 uF	Capacitor	C/0402
5	3	C3, C4, C14	33 pF	Capacitor	C/0402
6	5	C5, C15, C16, C19, C21	100 nF	Capacitor	C/0402
7	2	C6, C7	100 pF	Capacitor	C/0402
8	2	C8, C9	1.5 pF	Capacitor	C/0402
9	1	C10	3.3 pF	Capacitor	C/0402
10	1	C12	12 pF	Capacitor	C/0402
11	1	C13	47 pF	Capacitor	C/0402
12	2	C17, C18	22 pF	Capacitor	C/0402
13	1	D1		DIP6 Connector	Con6p_1mm
14	1	J1		SMA connector	SMB_V-RJ45
15	1	JTAG		DIP8 Connector	CN8P-2.0 - NoBoard
16	4	L1, L2, L5, L6	12 nH	Inductor	0402-A
17	2	L3, L4	18 nH	Inductor	0402-A
18	1	L7	3.3 nH	Inductor	0402-A
19	1	R1	56k	Resistor	R/0402
20	1	R2	47k	Resistor	R/0402
21	1	R3	10R	Resistor	R/0402
22	1	U1		CC1101	IC-QFN20-RTJ4X4
23	1	U2		MSP430G2533	IC-SSOP28(DBQ)

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8.3 PCB Layouts

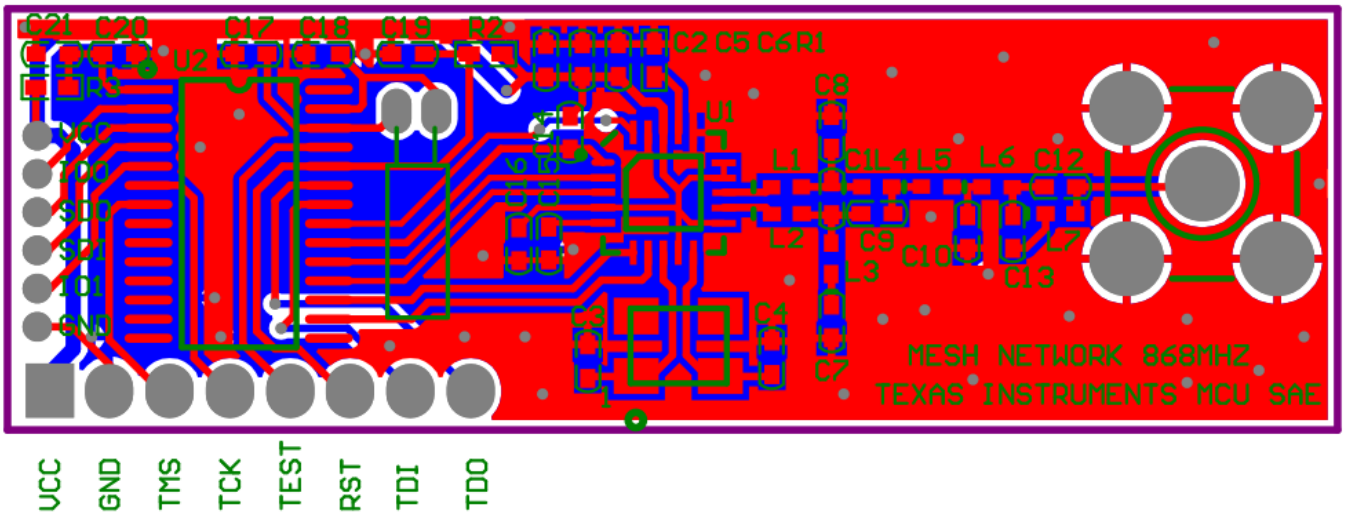

Figure 25. PCB Layouts

9 References

1. *MSP430G2533 - Mixed Signal Microcontroller* (SLAS734F)
2. *CC1101 - Low-Power Sub-1 GHz RF Transceiver* (SWRS061H)

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10 About the Author

FAN ZHANG is an MCU Systems Application Engineer at Texas Instruments, responsible for developing system solutions for IoT (Internet of Things) and industrial applications. Fan brings to this role his extensive experience in WSN (Wireless Sensor Network) applications, wireless network protocols, and system control logic. Fan got his master's degree in Pattern Recognition and Intelligent System in Donghua University.

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